The Digestive System
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Digestive System: Overview
- The alimentary canal or gastrointestinal (GI) tract digests and absorbs food
- Alimentary canal – mouth, pharynx, esophagus, stomach, small intestine, and large intestine
- Accessory digestive organs – teeth, tongue, gallbladder, salivary glands, liver, and pancreas
Digestive Process
- The GI tract is a “disassembly” line
  - Nutrients become more available to the body in each step
- There are six essential activities:
  - Ingestion, propulsion, and mechanical digestion
  - Chemical digestion, absorption, and defecation

Gastrointestinal Tract Activities
- Ingestion – taking food into the digestive tract
- Propulsion – swallowing and peristalsis
  - Peristalsis – waves of contraction and relaxation of muscles in the organ walls
- Mechanical digestion – chewing, mixing, and churning food
- Chemical digestion – catabolic breakdown of food
- Absorption – movement of nutrients from the GI tract to the blood or lymph
- Defecation – elimination of indigestible solid wastes
Regulation of digestion involves:
- Mechanical and chemical stimuli, stretch receptors, osmolarity, and presence of substrate in the lumen
- Extrinsic control by CNS centers
- Intrinsic control by local centers

Receptors of the GI Tract
- Mechano- and chemoreceptors respond to:
  - Stretch by the presence of food
  - Osmolarity – solute concentration
  - pH of contents
  - Presence of end products of digestion
- They initiate reflexes that:
  - Activate or inhibit digestive glands to secrete digestive juices
  - Mix lumen contents and move them along

Nervous Control of the GI Tract
- Intrinsic controls
  - Nerve plexuses near the GI tract initiate short reflexes
  - Short reflexes are mediated by local enteric plexuses (gut brain)
- Extrinsic controls
  - Long reflexes arising within or outside the GI tract
  - Involve CNS centers and extrinsic autonomic nerves

Peritoneum and Peritoneal Cavity
- Peritoneum – serous membrane of the abdominal cavity
  - Visceral – covers external surface of most digestive organs
  - Parietal – lines the body wall
- Peritoneal cavity
  - Lubricates digestive organs
  - Allows them to slide across one another
- Mesentery – double layer of peritoneum that provides:
  - Vascular and nerve supplies to the viscera
  - A means to hold digestive organs in place and store fat

Layers of the Alimentary Canal
- Mucosa
  - Secretes mucus, enzymes and hormones
  - Absorption of end products of digestion into blood
  - Protection against disease
- Submucosa
  - Dense connective tissue with blood, lymph and nerves
- Muscularis externa or muscularis
  - Responsible for peristalsis and segmentation
- Serosa
  - Actually the visceral peritoneum
Mouth
- Oral or buccal cavity:
  - Is bounded by lips, cheeks, palate, and tongue
  - Has the oral orifice as its anterior opening
  - Is continuous with the oropharynx posteriorly
- To withstand abrasions:
  - The mouth is lined with stratified squamous epithelium
  - The gums, hard palate, and dorsum of the tongue are slightly keratinized

Histology of the Alimentary Canal

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Lips and Cheeks
- Have a core of skeletal muscles
  - Lips: orbicularis oris
  - Cheeks: buccinators
- Vestibule – bounded by the lips and cheeks externally, and teeth and gums internally
- Oral cavity proper – area that lies within the teeth and gums
- Labial frenulum – median fold that joins the internal aspect of each lip to the gum

Palate
- Hard palate
  - Assists the tongue in chewing
  - Slightly corrugated on either side of the raphe (midline ridge) which helps to create friction
- Soft palate – mobile fold formed mostly of skeletal muscle
  - Closes off the nasopharynx during swallowing

Tongue
- Occupies the floor of the mouth and fills the oral cavity when mouth is closed
- Functions include:
  - Gripping and repositioning food during chewing
  - Mixing food with saliva and forming the bolus
  - Initiation of swallowing, and speech
- Intrinsic muscles change the shape of the tongue
- Extrinsic muscles alter the tongue’s position
- Lingual frenulum secures the tongue to the floor of the mouth
Salivary Glands

- Produce and secrete saliva that:
  - Cleanses the mouth
  - Moistens and dissolves food chemicals
  - Aids in bolus formation
  - Contains enzymes that break down starch
- Three pairs of extrinsic glands – parotid, submandibular, and sublingual
- Intrinsic salivary glands (buccal glands) – scattered throughout the oral mucosa
- Parotid – lies anterior to the ear between the masseter muscle and skin
  - Parotid duct – opens into the vestibule next to the second upper molar
- Submandibular – lies along the medial aspect of the mandibular body
  - Its ducts open at the base of the lingual frenulum
- Sublingual – lies anterior to the submandibular gland under the tongue
  - It opens via 10-12 ducts into the floor of the mouth
Saliva
- Secreted from serous and mucous cells of salivary glands
- A 97-99.5% water, hypo-osmotic, slightly acidic solution containing
  - Electrolytes
  - Digestive enzyme – salivary amylase
  - Proteins – mucin, lysozyme, defensins
  - Metabolic wastes – urea and uric acid
- Control of Salivation
  - Intrinsic glands keep the mouth moist
  - Extrinsic salivary glands secrete serous, enzyme-rich saliva in response to:
    - Ingested food which stimulates chemoreceptors and pressoreceptors
    - The thought of food
- Strong sympathetic stimulation inhibits salivation and results in dry mouth

Teeth
- Primary and permanent dentitions have formed by age 21
- Primary – 20 deciduous teeth that erupt at intervals between 6 and 24 months
- Permanent – enlarge and develop causing the root of deciduous teeth to be resorbed and fall out between the ages of 6 and 12 years
  - All but the third molars have erupted by the end of adolescence
  - There are usually 32 permanent teeth
- Teeth are classified according to their shape and function
  - Incisors – chisel-shaped teeth adapted for cutting or nipping
  - Canines – conical or fanglike teeth that tear or pierce
  - Premolars (bicuspids) and molars – have broad crowns with rounded tips and are best suited for grinding or crushing
- During chewing, upper and lower molars lock together generating crushing force
- Tooth Structure
  - Two main regions – crown and the root
    - Crown – exposed part of the tooth above the gingiva (gum)
    - Enamel – acellular, brittle material composed of calcium salts and hydroxyapatite crystals is the hardest substance in the body
      - Encapsules the crown of the tooth
    - Root – portion of the tooth embedded in the jawbone

Tooth and Gum Disease: Periodontitis
- Dental caries – gradual demineralization of enamel and dentin by bacterial action
  - Dental plaque, a film of sugar, bacteria, and mouth debris, adheres to teeth
  - Acid produced by the bacteria in the plaque dissolves calcium salts
  - Without these salts, organic matter is digested by proteolytic enzymes
  - Daily flossing and brushing help prevent caries by removing forming plaque
Tooth and Gum Disease: Periodontitis - continued

- **Gingivitis** – as plaque accumulates, it calcifies and forms calculus, or tartar
  - Accumulation of calculus:
    - Disrupts the seal between the gingivae and the teeth
    - Puts the gums at risk for infection
- **Periodontitis** – serious gum disease resulting from an immune response
  - Risk factors include smoking, diabetes, and oral or tongue or lip piercing

**Pharynx**

- From the mouth, the oro- and laryngopharynx allow passage of:
  - Food and fluids to the esophagus
  - Air to the trachea
- Lined with stratified squamous epithelium and mucus glands
- Has two skeletal muscle layers
  - Inner longitudinal
  - Outer pharyngeal constrictors

**Esophagus**

- Muscular tube going from the laryngopharynx to the stomach
- Travels through the mediastinum and pierces the diaphragm
- Joins the stomach at the cardiac orifice
- Glands secrete mucus as a bolus moves through the esophagus
Digestive Processes in the Mouth
- Food is ingested
- Mechanical digestion begins (chewing)
- Propulsion is initiated by swallowing
- Salivary amylase begins chemical breakdown of starch
- The pharynx and esophagus serve as conduits to pass food from the mouth to the stomach

Deglutition (Swallowing)
- Involves the coordinated activity of the tongue, soft palate, pharynx, esophagus and 22 separate muscle groups
- Buccal phase – bolus is forced into the oropharynx
- Pharyngeal-esophageal phase – controlled by the medulla and lower pons
  - All routes except into the digestive tract are sealed off
- Peristalsis moves food through the pharynx to the esophagus

Stomach – Gross Anatomy
- Chemical breakdown of proteins begins and food is converted to chyme
- Cardiac region – surrounds the cardiac orifice
- Fundus – dome-shaped region beneath the diaphragm
- Body – midportion of the stomach
- Pyloric region – made up of the antrum and canal which terminates at the pylorus
- The pylorus is continuous with the duodenum through the pyloric sphincter
Stomach – Gross Anatomy
- Greater curvature – entire extent of the convex lateral surface
- Lesser curvature – concave medial surface
- Lesser omentum – runs from the liver to the lesser curvature
- Greater omentum – drapes inferiorly from the greater curvature to the small intestine

Microscopic Anatomy of the Stomach
- Muscularis – has an additional oblique layer that:
  - Allows the stomach to churn, mix, and pummel food physically
  - Breaks down food into smaller fragments
- Gastric pits contain gastric glands that secrete gastric juice, mucus, and gastrin

Glands of the Stomach
- Gastric glands of the fundus and body have a variety of secretory cells
  - Mucous neck cells – secrete acid mucus
  - Parietal cells – secrete HCl and intrinsic factor

Stomach Lining
- The stomach is exposed to the harshest conditions in the digestive tract
- To keep from digesting itself, the stomach has a mucosal barrier with:
  - A thick coat of bicarbonate-rich mucus on the stomach wall
  - Epithelial cells that are joined by tight junctions
  - Gastric glands that have cells impermeable to HCl
- Damaged epithelial cells are quickly replaced

Digestion in the Stomach - The stomach:
- Holds ingested food
- Degrades this food both physically and chemically
- Delivers chyme to the small intestine
- Enzymatically digests proteins with pepsin
- Secretes intrinsic factor required for absorption of vitamin B₁₂

Regulation of Gastric Secretion
- Neural and hormonal mechanisms regulate the release of gastric juice
- Stimulatory and inhibitory events occur in three phases
  - Cephalic (reflex) phase: prior to food entry
  - Gastric phase: once food enters the stomach
  - Intestinal phase: as partially digested food enters the duodenum
- Cephalic Phase
  - Excitatory events include:
    - Sight or thought of food
    - Stimulation of taste or smell receptors
  - Inhibitory events include:
    - Loss of appetite or depression
    - Decrease in stimulation of the parasympathetic division
Regulation of Gastric Secretion - continued

- Gastric Phase
  - Excitatory events include:
    - Stomach distension
    - Activation of stretch receptors (neural activation)
    - Activation of chemoreceptors
    - Release of gastrin to the blood
  - Inhibitory events include:
    - A pH lower than 2
    - Emotional upset that overrides the parasympathetic division

- Intestinal Phase
  - Excitatory phase – low pH; partially digested food enters the duodenum and encourages gastric gland activity
  - Inhibitory phase – distension of duodenum, presence of fatty, acidic, or hypertonic chyme, and/or irritants in the duodenum
    - Initiates inhibition of local reflexes and vagal nuclei
    - Closes the pyloric sphincter
    - Releases enterogastrones that inhibit gastric secretion

![Stimulatory and Inhibitory Events Diagram](image-url)
Gastric Contractile Activity
- Peristaltic waves move toward the pylorus at the rate of 3 per minute
- Most vigorous peristalsis and mixing occurs near the pylorus
- Chyme is either:
  - Delivered in small amounts to the duodenum or
  - Forced backward into the stomach for further mixing

Regulation of Gastric Emptying
- Gastric emptying is regulated by:
  - The neural enterogastric reflex
  - Hormonal (enterogastrone) mechanisms
- These mechanisms inhibit gastric secretion and duodenal filling
- Carbohydrate-rich chyme quickly moves through the duodenum
- Fat-laden chyme is digested more slowly causing food to remain in the stomach longer

Small Intestine
- Gross Anatomy
  - Runs from pyloric sphincter to the ileocecal valve
  - Has three subdivisions: duodenum, jejunum, and ileum
  - The jejunum extends from the duodenum to the ileum
  - The ileum joins the large intestine at the ileocecal valve
- Microscopic Anatomy
  - Structural modifications of the small intestine wall increase surface area
    - Plicae circulares: deep circular folds of the mucosa and submucosa
    - Villi – fingerlike extensions of the mucosa
    - Microvilli – tiny projections of absorptive mucosal cells' plasma membranes

![Image](a) ![Image](b)
Intestinal Juice
- Secreted by intestinal glands in response to distension or irritation of the mucosa
- Slightly alkaline and isotonic with blood plasma
- Largely water, enzyme-poor, but contains mucus

Liver
- The largest gland in the body
- Superficially has four lobes – right, left, caudate, and quadrate
- The falciform ligament:
  - Separates the right and left lobes anteriorly
  - Suspends the liver from the diaphragm and anterior abdominal wall
- Liver: Associated Structures
  - Bile leaves the liver via:
    - Bile ducts, which fuse into the common hepatic duct
    - The common hepatic duct, which fuses with the cystic duct
      - These two ducts form the bile duct
- Liver: Microscopic Anatomy
  - Hexagonal-shaped liver lobules are the structural and functional units of the liver
    - Composed of hepatocyte (liver cell) plates radiating outward from a central vein
    - Portal triads are found at each of the six corners of each liver lobule
  - Portal triads consist of a bile duct and
    - Hepatic artery – supplies oxygen-rich blood to the liver
    - Hepatic portal vein – carries venous blood with nutrients from digestive viscera
  - Hepatocytes’ functions include:
    - Production of bile
    - Processing bloodborne nutrients
    - Storage of fat-soluble vitamins
    - Detoxification

Composition of Bile
- A yellow-green, alkaline solution containing bile salts, bile pigments, cholesterol, neutral fats, phospholipids, and electrolytes
- Bile salts are cholesterol derivatives that:
  - Emulsify fat
  - Facilitate fat and cholesterol absorption
  - Help solubilize cholesterol
- The chief bile pigment is bilirubin, a waste product of heme
The Gallbladder
- Thin-walled, green muscular sac on the ventral surface of the liver
- Stores and concentrates bile by absorbing its water and ions
- Releases bile via the cystic duct, which flows into the bile duct

Regulation of Bile Release
- Acidic, fatty chyme causes the duodenum to release:
  - Cholecystokinin (CCK) and secretin into the bloodstream
- Bile salts and secretin transported in blood stimulate the liver to produce bile
- Cholecystokinin causes:
  - The gallbladder to contract
  - The hepatopancreatic sphincter to relax
- As a result, bile enters the duodenum
Pancreas
- Location
  - Lies deep to the greater curvature of the stomach
  - Encircled by the duodenum and the tail abuts the spleen
- Exocrine function
  - Secretes pancreatic juice which breaks down food
  - Acini (clusters of secretory cells) contain zymogen granules with digestive enzymes
- Endocrine function
  - Release of insulin and glucagon

Pancreatic Juice
- Water solution of enzymes and electrolytes
  - Neutralizes acid chyme
  - Provides environment for pancreatic enzymes
- Enzymes are released in inactive form and activated in the duodenum
- Active enzymes secreted
  - Amylase, lipases, and nucleases
  - These enzymes require ions or bile for optimal activity
Regulation of Pancreatic Secretion
- Secretin and CCK are released when fatty or acidic chyme enters the duodenum
- CCK and secretin enter the bloodstream
- Upon reaching the pancreas:
  - CCK induces the secretion of enzyme-rich pancreatic juice
- Vagal stimulation also causes release of pancreatic juice

Digestion in the Small Intestine
- As chyme enters the duodenum:
  - Carbohydrates and proteins are partially digested
  - No fat digestion has taken place
  - Chyme is released slowly into the duodenum
  - Mixing is required for proper digestion
  - Virtually all nutrient absorption takes place in the small intestine

Motility in the Small Intestine
- The most common motion of the small intestine is segmentation
  - Initiated by intrinsic pacemaker cells
  - Moves contents steadily toward the ileoceleval valve
- After nutrients have been absorbed:
  - Peristalsis begins with each wave starting distal to the previous
  - Meal remnants, bacteria, mucosal cells, and debris are moved into the large intestine
- Control of Motility
  - Local enteric neurons of the GI tract coordinate intestinal motility
  - Cholinergic neurons cause:
    - Contraction and shortening of muscle layer
    - Distension of the intestine
  - The gastroileal reflex and gastrin:
    - Relax the ileoceleval sphincter
    - Allow chyme to pass into the large intestine

Large Intestine
- Has three unique features:
  - Teniae coli – three bands of smooth muscle
  - Haustre – pocketlike sacs caused by muscle tone
  - Epiploic appendages – fat-filled pouches of visceral peritoneum
- Is subdivided into the cecum, appendix, colon, rectum, and anal canal
- The saclike cecum:
  - Lies below the ileoceleval valve in the right iliac fossa
  - Contains a wormlike vermiform appendix
Colon
- Has distinct regions: ascending colon, hepatic flexure, transverse colon, splenic flexure, descending colon, and sigmoid colon
- The sigmoid colon joins the rectum
- The anal canal, the last segment of the large intestine, opens to the exterior at the anus

Valves & Sphincters of the Rectum and Anus
- Three valves of the rectum stop feces from being passed with gas
- The anus has two sphincters:
  - Internal anal sphincter of smooth muscle
  - External anal sphincter of skeletal muscle
- These sphincters are closed except during defecation
Bacterial Flora
- The bacterial flora of the large intestine consist of:
  - Bacteria surviving the small intestine that enter the cecum and
  - Those entering via the anus
- These bacteria:
  - Colonize the colon
  - Ferment indigestible carbohydrates
  - Release irritating acids and gases (flatus)
  - Synthesize B complex vitamins and vitamin K

Functions of the Large Intestine
- Other than digestion of enteric bacteria, no further digestion takes place
- Vitamins, water, and electrolytes are reclaimed
- Its major function is propulsion of fecal material toward the anus
- Though essential for comfort, the colon is not essential for life

Motility of the Large Intestine
- Haustral contractions
  - Slow segmenting movements that move the contents of the colon
  - Haustra sequentially contract as they are stimulated by distension of the colon
- Presence of food in the stomach:
  - Activates the gastrocolic reflex
  - Initiates peristalsis that forces contents toward the rectum
Defecation
- Distension of rectal walls caused by feces
  - Stimulates contraction of the rectal walls
  - Relaxes the internal anal sphincter
- Voluntary signals stimulate relaxation of the external anal sphincter and defecation occurs

Absorption
- Up to 10 L of food, drink, and GI secretions enter the GI tract daily
- Only 1 L or less reaches the large intestine
- Virtually all food, 80% of electrolytes and water absorb in the small intestine
- It is nearly impossible to exceed the absorptive capacity if the GI tract
- At the end of the ileum, all that remains is some water, indigestible food materials, and millions of bacteria
- The debris is passed on into the large intestine

Water Absorption
- Approximately 9 L of water, mostly derived from GI tract secretions, enter the small intestine daily
- Water is the most abundant substance in chyme
- 95% of water is absorbed in the small intestines by osmosis
- Normal rate of water absorption is 300-400 ml/hour
- Water moves in both directions across intestinal mucosa

Malabsorption of Nutrients
- Results from anything that interferes with delivery of bile or pancreatic juice
- Factors that damage the intestinal mucosa (e.g., bacterial infection)
- Gluten enteropathy (adult celiac disease) – gluten damages the intestinal villi and reduces the length of microvilli
  - Treated by eliminating gluten from the diet (all grains but rice and corn)
Developmental Aspects and Lifespan Changes

- During fetal life, nutrition is via the placenta, but the GI tract is stimulated toward maturity by amniotic fluid swallowed in utero
- At birth, feeding is an infant’s most important function and is enhanced by
  - Rooting reflex (helps infant find the nipple) and sucking reflex (aids in swallowing)
- Digestive system has few problems until the onset of old age
- During old age the GI tract activity declines, absorption is less efficient, and peristalsis is slowed
- Changes to the digestive system are slow and slight, and eventually include:
  - Teeth may become sensitive
  - Gums may recede
  - Teeth may loosen, break or fall out
  - Heartburn may become more frequent
  - Constipation may become more frequent
  - Nutrient absorption decreases
  - Accessory organs age but typically not necessarily in ways that effect health

Cancer

- GI cancers rarely have early signs or symptoms
- Metastasized colon cancers frequently cause secondary liver cancer
- Prevention is by regular dental and medical examinations
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- Forms from benign mucosal tumors called polyps whose formation increases with age
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